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THE SOIL AND THE PLANT

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PREFACE

THE purpose of this small book is to provide a simple introduction to the study of the soil for students in Farm Institutes and Agricultural Colleges. While it is written from the standpoint of the chemist, yet it is hoped that farmers and gardeners may also find in it something of interest.

The first chapter has been written to assist this class of reader. Throughout the book the attempt has been made to express the facts in the simplest possible manner. Such indeed is the art of teaching. Only three tables have been included. For two of these, I am indebted to the paper in the *Journal* of the Royal Agricultural Society on " Soil Analysis as a Guide to the Farmer ", by Mr. Morley Davies.

The author will soon complete a quarter of a century as Head of the Chemistry Department in the Seale Hayne Agricultural College. These notes are largely the lectures on the Chemistry of Soils given to students taking the diploma courses in agriculture and horticulture. Of the two years spent on these courses, the first year is largely spent in providing a foundation in elementary chemistry, biology, physics and mechanics, and bookkeeping. With a new spirit in education, and a greater will to learn, it may be hoped that in the future a higher standard of intellectual attainment will be possessed by entrants to the Colleges. When this is so, more time can be given to the application of chemistry to agriculture, and students leaving the Colleges will be better equipped for dealing with the problems that will present themselves in their new spheres of work.

The author owes much to the works of the late Sir Daniel Hall and to the various editions of Sir E. John Russell's *Soil Conditions and Plant Growth.*

E. V.

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CHAPTER I

BASIC PRINCIPLES OF AGRICULTURAL CHEMISTRY

THE science of chemistry deals with the composition of all the materials in the universe and with the changes these stuffs or substances undergo when they are acted on by other substances such as air, water, heat, or other agents.

Agricultural Chemistry, then, is concerned in this way with those substances or stuffs that are of use to the farmer. This will include :

1. A study of the composition of the soil and the changes it undergoes when cultivated.
2. The nature of the plant, the chemical changes during growth and maturity and its effects on the soil.
3. The chemical nature and effects of fertilisers on the soil and the crop.
4. The feeding value of crops and the changes they undergo during digestion.
5. The composition of animal and dairy products, such as meat, milk, butter, and cheese.

Evidently a very large number of substances are included. The study of these seems a gigantic undertaking. We all know that the English alphabet consists of only twenty-six letters but by combinations of these the hundreds of thousands of words in the dictionary are made. So also with agricultural chemistry. From a very few simple substances called " elements ", all the substances or compounds known to agriculture are formed. These elements are single bodies, incapable of decomposition but able to unite with one another to form an immense number of compounds.

We now see the difference between elements and compounds. Many of the elements are well known and in everyday use ; for example, iron, aluminium, tin, lead, and copper. Less familiar are calcium, magnesium, sodium, and potassium. All these substances are known as metals. They are usually shining substances, good conductors of heat and electricity, and capable of being made into wires or hammered into sheets. They are all solid substances mostly requiring a very high temperature to make them melt.

The following are less familiar, but nevertheless important elements : hydrogen, oxygen, nitrogen, phosphorus, sulphur, carbon, silicon, boron, chlorine, arsenic, and iodine. The first three are gases. Hydrogen is an inflammable gas which combines with oxygen with explosive violence to form water. Nitrogen and oxygen are mixed together in the air. The other gas in the list is chlorine, a greenish-yellow, poisonous gas obtained from salt. The other elements mentioned are solids which readily burn in the air. Sulphur and carbon are well known. These elements are called non-metals. They do not conduct heat and electricity and in many ways have opposite characteristics to metals. The metals and non-metals readily combine with one another. Compounds of the metals with oxygen are called oxides ; with sulphur, sulphides ; and so on with the other non-metals.

This short list includes almost all the chemical elements of importance in agriculture. It has been mentioned that several of them burn in the air. This burning is chemical combination with oxygen and the oxide of the element is formed. Oxides are very simple compounds but of great importance. Water is the oxide of hydrogen. It is a neutral liquid with refreshing taste. Other oxides are very different.

Generally the oxides of the non-metals, such as the oxides of carbon, sulphur, and phosphorus, are gases which dissolve in water to form acids, that is liquids with sour taste which are often capable of dissolving metals.

How different are the oxides of metals. Rust is the oxide of iron. Lime, that is quicklime, or burnt-lime, is the oxide of calcium. The oxides of metals are mostly insoluble in water but usually soluble in acids, which they neutralise. They are said to be basic. Those oxides of metals which are soluble in water are alkaline in nature; they are the commonest substances used for neutralising acids. Examples are : caustic soda, caustic potash, and hydrated lime.

It will be realised that an acid is more complex than an oxide, since it is usually an oxide of a non-metal dissolved in water. All acids contain hydrogen. When acids are neutralised with the oxides of metals a neutral substance called a salt is formed. Thus, if sulphuric acid is neutralised with lime, sulphate of lime or calcium sulphate is formed.

Similarly we obtain carbonates from carbonic acid, phosphates from phosphoric acid, silicates from silicic acid, nitrates from nitric acid, and chlorides from hydrochloric acid. (We shall meet with examples of these in succeeding pages.)

Let us summarise this brief chapter.

The simplest, undecomposable substances are the elements. By the various combinations of about twenty of these all the materials used or concerned with agriculture are formed. Elements may be classed as metallic and non-metallic. The former are solids but many of the latter are gases. Metals can combine with non-metals to form compounds. Most metals unite readily with oxygen to form oxides. Non-metallic elements also unite with oxygen. Such oxides are acid-forming; they form acids when dissolved in water.

The oxides of metals are different. They neutralise acids, forming salts. They are basic oxides.

A clear understanding of the nature of oxides of metals and non-metals is essential to the study of the soil. The following oxides will come under consideration: Sodium oxide or soda, alkaline or basic, very soluble in water. Potassium oxide or potash, alkaline or basic, also very soluble. Calcium oxide or lime, alkaline or basic, less soluble. Magnesium oxide or magnesia, alkaline or basic, slightly soluble. Iron oxide, or ferric oxide, basic and insoluble, a sesquioxide, rust or rouge, a red oxide. Aluminium oxide or alumina can be basic or acidic. Silicon dioxide or silica, quartz or sand, a weak acidic oxide. These two oxides of aluminium and silicon are able to form complex alumino-silicic acids. Such acids are weak and non-corrosive. They will combine with the very basic oxides such as potash and lime. Other acidic oxides of importance are carbon dioxide or carbonic acid gas and phosphoric oxide or phosphoric acid. In this list it will be seen that we pass from very basic or antacid oxides to less basic, and even to one which can be both basic and acidic, and finally to acidic oxides.

CHAPTER II

THE FORMATION OF SOIL

The Soil.—If we dig a hole in the ground we see that the top soil is dark in colour and that it consists of fine particles. The depth of this kind of soil may vary from a few inches to two feet. If we continue digging we see that the lower soil, or sub-soil, has a different colour ; it is not so dark and contains more stones. On digging a little deeper, we reach the hard rock.

There is much evidence to prove that the soil has been formed by the crumbling of the rock during a period of hundreds or thousands of years. The process of crumbling or weathering can be seen by examining places where the soil is exposed, such as quarries and cuttings.

Rocks are not simple substances but generally mixtures of substances cemented together. Examine a piece of granite. You will see that it contains transparent crystals of quartz, flat shining plates of mica, and a light-coloured substance known as felspar.

These components of the rock are called minerals. By the removal of the cementing material the rock is broken up. How is this effected ? There are many agencies at work. Among them are—

(1) Chemical action.
(2) The solvent action of water.
(3) The mechanical effect of running water.
(4) Frost.
(5) Lichen and mosses.

(6) Roots.
(7) Earthworms, insects, and microbes.
(8) Heat.

The chemical action of the oxygen in the air changes a harmful oxide of iron into a harmless oxide, and at the same time removes a kind of cementing material.

One of the most effective agents in the disintegration process is that of water containing dissolved carbonic acid gas. This dissolves the minerals of most rocks. In limestone districts vast caves have been formed. Within the cave the water coming through the roof dissolves a little of the limestone, loses its carbonic acid as it falls, and as a result, a deposit of limestone grows from the ground upwards and another from the roof downwards. It is estimated that it takes a thousand years for these deposits to grow an inch. Running water carries along stones and debris, thus causing rock fragments to grind against one another like the pebbles on the shore. The constant freezing and thawing of water in the interstices of rocks causes them to be burst asunder by the force of the expansion. Rocks on which lichen and mosses grow will be found to have broken fragments near the roots. Roots of trees often penetrate rock fissures and help to widen the crevices and break up the rock. We must remember that the soil has an immense population of living creatures always at work and these assist the process of crumbling. Lastly, the temperature of rocks is always changing. Sudden changes result in expansion and contraction which assist the process of cleavage.

These various agents have been at work for thousands of years. During that time earthquakes, floods, volcanic eruptions, ice movements, and periods of great heat have occurred and these have formed the hills and dales, the barren crags, and fertile valleys of to-day.

Rocks and Minerals.—The science of geology deals with the study of rocks and that of mineralogy with the composition of minerals. We should see a close relationship between the geology of a district and the fertility of the soil. Many books have been written illustrating this relationship.

We shall consider but a few out of hundreds of important minerals. They can mostly be regarded as compounds of the oxides of elements such as potassium, calcium, magnesium, aluminium, and iron with the oxide of silicon or silica.

The chief minerals in the earth's crust are :

Felspars.	Potassium aluminium silicates.	About	48	per cent
Quartz.	Oxide of silicon.	,,	35	,,
Mica.	Potassium aluminium silicates.	,,	8	,,
Talc.	Magnesium silicate.	,,	5	,,
Serpentine.	Magnesium silicate.	,,	1	,,
Limestone and Magnesian Limestone.	Calcium and magnesium carbonates.	,,	1	,,
Augite, Hornblende, Olivine and Diallage.	Magnesium silicates.	,,	1	,,
Clay, Kaolin or China Clay.	Hydrated silicate of alumina.	Less than	1	,,

The Felspars.—Since these have a great influence on the composition of the soil and on its fertility, we must consider their chemical nature. Usually they contain three different types of oxides. First a metallic, or strongly basic oxide such as potash, soda, lime, or magnesia. Secondly, the oxide of aluminium which can behave either as a feeble or as a weak base; and lastly, the acidic oxide, silica. These felspars will then act as neutral substances in the soil and will supply potash, magnesia, and lime. It will be understood that if the potash or lime is removed, then the altered felspar will become acid in character. In actual fact the potash is readily dissolved by the carbonic acid in the water in the soil, and when it is all removed kaolin or china clay is the result — a substance with acidic properties.

Quartz.—This is the simplest of minerals, being practically pure silica or oxide of silicon. It is very hard and is insoluble in acids. It forms sand when powdered. It resists weathering and so all soils contain it.

The Micas.—These are more resistant than the felspars and slowly give up potash and lime to the soil. The soil will therefore always contain quantities of unchanged and partly changed felspars and micas. Fertile soils usually contain minerals like these, with lime as one of the combined oxides.

Olivine, Talc, and Serpentine.—These are silicates of magnesium. In districts where the soil is mainly formed from serpentine there will be a lack of potash and therefore of fertility.

Calcium and Magnesium Carbonates.—These are the principal basic or neutralising oxides in the soil and serve to keep the soil in the best condition. These effects will be considered in detail in a later chapter.

Oxides of Iron.—The commonest oxide of iron is rust. The red, yellow, and brown soils owe their colour very largely to the presence of oxides of iron, often hydrated or combined with water. As already stated, iron oxides are present in many of the other minerals. Very few soils are free from iron compounds. Iron is essential for the feeding of plants and animals.

Minerals containing Phosphorus.—Phosphates of lime, of aluminium, and of iron are present in the soil. Often the amount present is small. For reasons that will be considered later, the phosphate of lime is of greater value than the others.

In this chapter we have seen that the soil is formed by the weathering of rocks and the liberation of minerals. Of the minerals the felspars are most abundant. They bring to the soil potash, soda, lime, and magnesia. When completely weathered they may form clay or alumino-silicic acid. The micas are similar to the felspars but more resistant. Quartz is very resistant and all soils contain sand. Limestone or calcium carbonate is fairly abundant and important for fertility. Oxides of iron give colour to soils and are present in most soils. Phosphates are least abundant.

The soil thus formed by the breaking of rock fragments will consist chiefly of silicates, that is of compounds of the weak silicic acid with alumina and the more basic oxides, lime, magnesia, and potash. Such soil will be generally neutral or slightly acid. If much lime is present it will probably be alkaline. Rarely will it be excessively acid or alkaline.

CHAPTER III

THE FINENESS OF SOIL PARTICLES

WE must now confine our attention to that part of the soil which is cultivated and which we have already called the top soil.

What are the effects of the constant ploughing, harrowing, rolling, and other operations of tillage on this portion of the soil ? Examine a handful of soil. You will see that it contains particles of various sizes. Small stones, gritty particles, and a certain amount of very fine earth will be present. Rootlets will also be seen and the mass will have an earthy smell. This is due to the presence of vegetable matter, the dark stuff that coats all the soil particles. Soils are classified according to the fineness of the particles present. The coarse particles are those of gravel and sand. Soils in which these predominate are not fertile; they cannot retain water and contain little plant food. The sand dunes near the coast are barren. There is little vegetable matter binding the particles together. The finest particles in the soil are the clay particles. As the proportion of these increases the nature of the soil changes. If the soil is mostly sand but has sufficient clay and vegetable matter, it may have some value as a market garden. With more clay and other favourable conditions potatoes can be grown as on sandy loams. Loams are soils with sufficient sand, clay, and vegetable matter.

When the proportion of clay preponderates, then the soil becomes more difficult to cultivate. The movement of water is hindered. Often such soils have to be drained. They are more suited for crops such as wheat and mangels. When they are too difficult or too expensive to be cultivated they are left down to grass, and are often greatly improved by applications of lime and basic slag. Why are these clay soils so different ? To understand this we must consider the question of the size of particles more closely. Take a handful of any finely ground material such as flour. It will absorb a great deal of water. It becomes plastic and can be moulded. With more water it becomes sticky. It swells when wetted and shrinks on drying. The clay particles have similar properties.

Suppose we have a cube of some material that can be cut, such as soap, and that the length, depth, and height is 1 inch. If you could lay each of the six sides flat they would cover a surface or area of 6 square inches. If you now cut the cube into two equal parts you make two new surfaces and the surface area is now 8 square inches. If you make a thousand cuts in the same way you will obtain thin sheets of soap with a surface area of 2006 square inches. If you cut each of these square sheets a thousand times you will obtain threads each an inch long and you will have increased the surface area again by 2000 square inches. Lastly, if these threads are cut a thousand times you obtain tiny particles and again the surface has been increased by yet another 2000 square inches. The conclusion is that powders have an enormous area, hence they are able to absorb large quantities of water. In fact the possession of this great surface gives them special properties. The finest particles, that is those of clay, are called colloids, meaning glue-like substances. The surface area of these is enormous. It is estimated that if the particles in a cubic foot of soil could be spread out on a level surface they would cover an acre.

Thus by cultivating the soil its surface area is greatly increased. It can absorb water to a greater extent; air can enter and bring about necessary chemical changes; the plant roots have not to draw the food they require from the small surface of a large lump or clod which they try to penetrate, but can spread over the vast area made by the surface of the fine particles to which the root hairs become so firmly attached. Each plant has, as it were, a field to itself in the soil from which it can suck up the nutrients it requires.

Mechanical Analysis of Soils.—Soil scientists have tried to classify soils according to the amounts of sand, clay, etc., present. By international agreement it has been decided that all particles having a diameter greater than 2 millimetres shall be classed as stones and gravel. The other fractions are as follows :

Stones.	Above 2 mm. diameter.
Coarse Sand.	Diameter between 2·00 mm. and 0·200 mm.
Fine Sand.	Diameter between 0·20 mm. and 0·020 mm.
Silt.	Diameter between 0·02 mm. and 0·002 mm.
Clay.	Diameter less than 0·002 mm.

The principles underlying the determination of the proportions of sand, silt, and clay, that is the mechanical analysis of the soil, are as follows :

The soil particles must first be dispersed by removing all binding material, such as carbonate of lime, and vegetable matter or humus. Treatment with dilute hydrochloric acid removes the lime and hydrogen peroxide is used to remove the humus. The soil is washed to remove the acid and then thoroughly shaken with water made alkaline with ammonia solution. This solution assists in the dispersion of the clay particles. The soil and liquid is now filtered and washed with hot water. It is transferred to a sieve with square apertures 0·2 mm. wide, and gently rubbed while being washed with a jet of water. The liquid passing through is collected, made alkaline with ammonium hydroxide, and shaken for 24 hours to complete the dispersion of the fine particles. The fraction remaining on the sieve is " coarse sand ". The dispersed liquid from a known weight of soil is made to a definite volume, usually 1000 ml., in a tall cylinder with water, well shaken and allowed to stand. The large particles settle quickly. It has been calculated that it takes 4 minutes 48 seconds for the sand to pass below a depth of 10 cm., leaving the clay and silt in suspension. A known volume of the liquid, 20 ml. containing the silt and clay only, is removed from a point 10 cm. below the surface, the water evaporated, and the weight of silt and clay found. The amount in the whole volume of liquid is then calculated. The rest of the liquid is again shaken and allowed to stand. After another 8 hours' interval a sample containing clay only is removed from a depth 10 cm. below the new level and the amount present found in a similar manner. The sand settles so quickly that it is easy to pour off the silt and clay in the remainder and determine the quantity of fine sand present.

We have now seen that the soil consists of particles of various sizes. Excluding stones, gravel and sand are the coarse particles. The clay particles are exceedingly small. This causes them to have an enormous surface area which gives them special properties. They are colloids and are able to absorb water, to swell when wetted, and to shrink on drying.

The coarse and fine particles are so mingled in the soil as to form a fine structure with minute air spaces like a sponge. The result of cultivation and manuring and cropping should be to make and retain a crumb structure in which the particles are coated with humus as a binding material. Without this the soil may become dusty, removed by winds, and the conditions for rapid loss of soil by erosion brought about. This has happened to an alarming extent in many parts of the world.

The Weight of the Soil.—If we assume that the soil is cultivated to a depth of 9 inches, then in ploughing or digging an acre of soil a volume of soil equal to $4840 \times 9 \times \frac{3}{4}$ cubic feet has been broken up. A cubic foot of water weighs 1000 oz., or 62½ lb. We may assume the soil with its air spaces to have the same density as water, or, in other words, that equal volumes of soil and water will have the same weight. An acre of soil 9 inches deep will therefore weigh $4840 \times 9 \times \frac{3}{4} \times 62\frac{1}{2}$ lb., which is 911 tons. It will be sufficiently accurate for our purpose to consider an acre of cultivated soil as weighing 1000 tons. A gardener with a 10-rod allotment will realise that he has to break up no less than 62½ tons of soil. The need for mechanical power in farming operations will also be appreciated.

CHAPTER IV

THE FOOD REQUIREMENTS OF PLANTS

THE chemical analysis of plants shows the presence of certain elements which have combined in various ways to make up the substance of the plant. These elements have come from the air, from water, and from the soil. From the air the plant obtains its carbon and this makes up the greater part of the plant. Under certain conditions, which will be discussed later, certain plants can also obtain nitrogen from the air. Most plants obtain nitrogen from the organic matter or humus coating the soil particles.

Water supplies the elements hydrogen and oxygen. All plants in active growth contain a large amount of water.

From the soil comes a greater number of elements which are left in the ash when the plants are burned. Here will be found sodium and potassium, calcium and magnesium, iron and aluminium, manganese, copper, phosphorus, sulphur, silicon, chlorine, and traces of other elements. Most soils contain an abundance of the elements necessary for the growth of plants and the plants are able to extract this mineral food sufficient for their needs except for four elements. Only in the endeavour to obtain adequate amounts of nitrogen, calcium, potassium, and phosphorus does there appear to be difficulties. These elements are locked up in the soil. By the various operations in tillage and by the action of air, water, and by freezing and thawing they are very slowly released. So slow are these processes that the plants cannot obtain enough for maximum growth and so the application of fertilisers containing nitrogen, potassium, phosphorus, and calcium is necessary.

Other Requirements of Plants.—Like all other living things plants also require light and warmth, air and water, and the defeat of enemies such as pests, diseases, and poisons.

Light.—This comes from the sun. Under its influence each green leaf becomes a chemical factory transforming the simple substances water and carbon dioxide (CO_2) into sugars, starch, and cellulose. In this way the bulk of the plant is built up. The green colouring matter of the leaf, the chlorophyll, plays an important part in this transformation. Many other complex changes also take place by which such substances as proteins or albuminoids, vitamins, oils, and even poisonous alkaloids, are found. In the absence of light the leaves become bleached and growth soon ceases.

Heat.—Provided other factors for growth are adequately supplied, such as water and food, growth is greatest and quickest where there is warmth. The tropical regions illustrate this, and so also does the work carried on in greenhouses and on hot-beds or in frames. The soil is warmed by the sun : the land that can best receive the sun's rays will be warmest. Land that slopes to the south will therefore be found to be warm and to produce early crops. Soils with a northerly slope will be coldest and harvests will be late. The soil will be warmed also by the chemical decomposition or decay of vegetable matter — the " humus " — and by applications of farmyard manure and its subsequent decomposition.

Air.—It has already been stated how the leaves utilise the carbon dioxide in the air to form the bulk of the plant. Air is also required during the germination of seeds to remove slowly the outer coats of the seeds. The roots also require air. When plants are grown in water to which various nutrients are added, that is in water cultures, air has to be bubbled in the neighbourhood of the roots or the plants must be lifted out of the water each day. Sandy soils allow the air to enter more easily than clay soils, and the root system in such soils is more developed than in clay soils.

The air in the soil does not differ much from that above it. Nearly 80 per cent of it is nitrogen gas ; rather less than 20 per cent is oxygen. There will be more carbon dioxide in the air in the soil than in ordinary air. The amount of this gas will vary with the nature of the soil and with the amount and rate of decomposition of the " humus ". This carbon dioxide plays a very important part in bringing the mineral matter in the soil into solution and thus available to the plant. With water the gas forms a weak acid solution which is able to dissolve slowly substances such as potash and phosphate from the soil particles.

Average crops remove from 2 to 5 tons per acre of carbon dioxide from the air. This is replaced by that which is breathed out by human beings and animals and by the gases from the burning of wood and coal.

The many millions of bacteria in the soil also require air for growth and multiplication. They assist in bringing about the various changes in the organic matter in the soil.

Water.—This is the greatest factor in plant growth. The quantities of water that pass through the roots and out through the leaves are very great. This is seen from the following table :

WATER TRANSPIRED IN TONS PER ACRE

Wheat	600	Mangels	900
Barley	550	Potatoes	450
Turnips	400	Meadow hay	375

These large amounts of water are supplied by the rain. An inch of rain, that is enough to cover 1 acre to the depth of 1 inch, would supply 100 tons. It would thus appear that a rainfall of 10 inches would provide 1000 tons of water and this would be sufficient for a crop of mangels. It must, however, be pointed out (*a*) that the crop is not there during the whole of the year, (*b*) in this country most of the rain falls in autumn and winter, (*c*) that the need for water is greatest in the rapidly growing period, (*d*) that much of the rain runs off the surface and only part of it will percolate through the soil. Some of this will pass down to where the soil is saturated ; the remainder will fill, or partly fill, the pore spaces.

It can be stated that the kind of crops that can be grown in a district depend on the rainfall. Where there is little or no rainfall the land must be irrigated and careful control of the water supply is necessary. Where there is too much water the land must be drained.

Two factors determine the availability of the soil water to the plant :

(1) The respective pulls or suction pressures exerted by plant and the soil.
(2) The ease with which water can travel in the soil and replace that which has been taken up by the roots.

Suction Pressure by the Plant.—When the moisture in the soil has been so much reduced that the plants wilt even when the atmosphere is moist, the moisture content of the soil is called the wilting coefficient, and the suction pressure by the plant is then about twenty times the pressure of the air, or about 280 lb. to the square inch.

Suction Pressure by the Soil.—This varies enormously with the water content of the soil. It is more than 130 atmospheres, or 1820 lb. to the square inch, at the wilting coefficient. The soil in this condition holds the water with greater force than the plant can exert to obtain it. The less water present in the soil the more tenaciously the soil holds it.

The Movement of Water in the Soil.—Water passes down the cracks in clay soil and through the pore spaces in sands and silts. It has been found that if the water-level was 12 inches below the surface the growth of grass was good, but was poor when the water was at 20 inches depth and that the grass failed when the water was 26 inches below. Other experiments showed that on arable land 20 inches was most favourable, at 32 inches crops were uncertain, and at 40 inches they failed. A clay soil may be seen cracking with drought when only a few feet away from a stream. These facts have led to a reconsideration of the views formerly held as to the movements of the water in the soil. Heretofore it was thought that the rise and movement of water was brought about by capillarity, by the agency of thin films of water, and the transfer of water from thick films at lower depths to the thin films near the surface where the water had been lost by evaporation. It was considered that water could rise in this way several feet.

While it is still true that capillarity impedes the downward-flow of water by gravity, it is not sufficient to bring the water to the surface nor to distribute the water.

This water problem is one of great complexity and new facts will gradually become known to bring about a clarification of the ideas now prevalent. The supply of water to the plant depends on the rainfall and on the absorbing and retaining power of the soil. The value of humus or organic matter for this purpose will therefore be realised.

CHAPTER V

THE REQUIREMENTS OF PLANTS: NITROGEN

Nitrogen.—The dark-green colour of the leaves of plants shows that they are obtaining soluble nitrogenous compounds which are passing into the roots. These soluble nitrogen compounds are being formed from the " humus " or organic matter by its decay in the soil.

In this chapter we shall consider this complex process. It may be stated at the outset, however, that it is a very slow one, too slow in fact for the needs of most crops, with the result that the farmer and market gardener take care to supply the plants with a quick-acting nitrogenous fertiliser such as sulphate of ammonia or nitrate of soda. Indeed, so rapid are these in action that great care must be taken to avoid excess, which would produce an abundant growth of leaf, soft and sappy, readily attacked by insect and fungoid pests. The organic manures, such as farmyard manure and bone meal, have the advantage that they supply a slow but steady and continuous amount of nitrogen.

The Decomposition of the Organic Matter.—Earthworms mix the constituents of the soil. They drag in leaves and pass a great deal of soil matter through their bodies, then throw it out in the form of worm-casts. These casts are much more numerous on lawns and grassland and on soils which are well limed. The worms prepare the organic matter for further attack by the millions of other organisms which dwell in the soil.

The organic or vegetable matter in its undecomposed state has much more carbon than nitrogen. This nitrogen is in combination with hydrogen in compounds of great complexity, such as the proteins or albuminoids. It is in this form that man and animals require the nitrogen in their food for body-building. Plants, however, require the nitrogen in the simplest possible state, in the form of soluble compounds that dissolve in the soil water and pass into the root system.

The simplest compounds of nitrogen are those of ammonia (NH_3), and nitrates such as sodium nitrate ($NaNO_3$).

It will now be seen that the organic matter has to change in such a way that the simplest nitrogen compounds are formed and the nitrogen unlocked from complex organic matter to feed the new plant.

If the carbon in the organic matter in the soil is more than twelve times the amount of the nitrogen, then the nitrogen remains locked up in the protein form. In most cultivated soils the proportion of carbon to nitrogen is ten to one, and under these circumstances nitrate is produced.

It would follow from this that if fresh straw were ploughed under, the nitrogen in the soil would be less available until much of the straw had been rotted or slowly burned away so as to reduce the high carbon content and thus allow the process of nitrate formation to proceed.

The chief constituent of straw, and indeed of other organic matter, is cellulose. Paper is made from wood-pulp; it is practically pure cellulose. The speed of decomposition of cellulose by micro-organisms in the soil depends on the amount of nitrogen present. In making artificial manure from straw and in making compost heaps the process of decay is greatly helped by adding nitrogenous material; in the former case by the addition of sulphate of ammonia.

The more resistant kind of cellulose from woody matter is known as lignin. Its decomposition results in the formation of the black material or " humus ". This contains about 50 per cent carbon and 5 per cent nitrogen, probably present as protein. The humus is present as a thin slime round the particles of soil. By the action of various micro-organisms this is changed to ammonium compounds, if the ratio of carbon to nitrogen does not exceed ten to one. This process is termed " ammonification ". Little ammonia is ever found in the soil, so the process does not stop at this stage.

Nitrification.—Other organisms, chiefly bacteria, convert the ammonium compounds into nitrites and then into nitrates. This process is oxidation in two stages :

$$2NH_3 + 3O_2 = 2HNO_2 + H_2O. \quad \text{Nitrous Acid.}$$
$$2HNO_2 + O_2 = 2HNO_3. \quad \text{Nitric Acid.}$$

The nitric acid thus formed would be neutralised by the bases in the soil, in particular by the calcium carbonate with the formation of calcium nitrate, a substance readily soluble in water and easily available to the plant. While the production of ammonia in the soils is a very slow process, the nitrification process is very rapid.

One of the chief organisms that bring about the change from ammonia is called *Nitrosomonas*, while that concerned in the second state producing nitrate from nitrite is called *Nitrobacter*. When there is no crop to take up the nitrate, or if the crop does not remove it rapidly enough, it is gradually washed away. Nitrogen in the soil is in this way being continually lost in the drainage water.

Loss of Nitrogen from Soils.—We have already seen that straw is more rapidly decomposed in the presence of nitrogenous matter. Certain kinds of micro-organisms use the nitrogen to build up in their own substance complex nitrogen compounds. Other kinds will bring about the reverse of nitrification. They will in fact remove the oxygen and so change or reduce the nitrates to compounds with less or no oxygen such as oxides of nitrogen, nitrogen gas, and ammonia : $2HNO_3 + 3H_2 = 6H_2O + N_2$. This process is called " denitrification ".

It occurs, or is most likely in soils supplied with large amounts of easily decomposable organic matter such as farmyard manure. These conditions prevail in heavily manured market gardens.

To sum up, readily available nitrate is formed by the slow decomposition of the organic matter. This may be (*a*) taken up by crops, (*b*) lost in the drainage water, (*c*) taken up by bacteria and made available, (*d*) transformed to the unavailable gaseous form when much organic matter is present.

Amounts of Nitrogen removed by Crops.—It has already been stated that the organic matter or humus is the storehouse of nitrogen. What stock of nitrogen is present in an average soil ? This question presents no great difficulty to the analyst. When stated as a percentage the amount usually found appears to be very small. Most arable soils are found to contain from 0·15 per cent to 0·2 per cent, and soils from grassland from 0·2 per cent to 0·5 per cent.

Let us see if we can make this clearer by considering the amounts present in an acre of soil. We have already seen that an acre of soil to a depth of 9 inches represents about 1000 tons ; this means that if 0·15 per cent of nitrogen is present it is no less than 1½ tons per acre. Very few soils have less, and many have as much as 4 tons per acre.

From the yield of any particular crop and an analysis of it the chemist can find how much nitrogen, potassium, phosphorus, and lime are removed by the crop. Here are the figures for the common farm crops:

Crop	Nitrogen, lb.	Phosphoric Acid, lb.	Potash, lb.	Lime, lb.	Magnesia, lb.
Wheat .	60	20	30	10	7·0
Barley .	50	20	35	10	7·0
Oats . .	50	20	45	12	8·7
Hay . .	50	12	50	32	15·0
Clover hay .	100	25	90	90	28·0
Beans .	100	30	70	30	10·0
Turnips .	140	33	150	75	10·0
Swedes .	100	22	80	42	10·0
Mangels .	150	53	300	43	42·0
Potatoes .	46	22	75	3	7·0
Broccoli .	215	80	250	100	—
Brussels sprouts	190	65	170	143	—

It will be seen that the quantities of nitrogen removed per acre are very small compared with the amounts present in the humus. In fact the stock of nitrogen is sufficient for more than a hundred crops of wheat.

We can now understand how allotment holders can grow crop after crop on the same plot of land and how at Rothamsted it has been possible to grow wheat on an unmanured plot year after year since 1852.

We observe also that the crops vary considerably in their demands for nitrogen and the other nutrients which they remove from the soil. The heavy demands made by crops like mangels, broccoli, and brussels sprouts are particularly noteworthy.

In spite of the huge store of nitrogen, farmers know that corn crops will benefit in springtime from a top dressing of a nitrogenous fertiliser. This shows how slowly the humus gives up its store of nitrogen to the plant, too slowly in fact for satisfactory growth, and hence the need for feeding the plant.

What the Plant does with the Nitrogen.— A plant is a food factory. It manufactures, from simple chemical substances taken in by root and leaf, very complex compounds which serve to feed both man and animals.

In the leaves are produced sugars and starch and cellulose. The sugar and starch pass to the part beneath the ground in crops such as sugar beet, potatoes, and mangels. These crops serve to produce energy in the animal and also for fattening. The roots take up the nitrates and use them to build up those complex compounds known as albuminoids or proteins which serve as flesh-formers.

Most farm crops yield much more starchy materials than proteins and farmers have to rely on the high protein content of pasture grass, or to feed imported oil cakes, or grow beans, lucerne, and linseed to obtain sufficient protein for flesh and milk production. Most of the nitrogen taken in by the animal in its food is voided or excreted and goes back to the dung-heap. Some of it is sold off from the farm with the animals and in the crops, but often a great deal is lost owing to the lack of care in the storing of the farmyard manure and the utilisation of liquid manure.

In the next chapter we shall consider how the soil can gain nitrogen to make good in some degree the losses already mentioned.

CHAPTER VI

HOW THE SOIL GAINS NITROGEN

In the air above the land there are vast stores of nitrogen gas. Air is also present in the numerous spaces between the soil particles. In this form the nitrogen is useless for feeding plants. The element must be combined with other elements to form a soluble compound before it can be of value as a nutrient.

Chemists have succeeded in combining nitrogen with oxygen and from that oxide they have manufactured nitric acid and nitrates. They have also been able to combine nitrogen with hydrogen and so produced ammonium compounds. These we know to be valuable fertilisers. In the soil there are micro-organisms which can bring about somewhat similar chemical changes. The increasing fertility that results from growing such crops as clover, beans, peas, vetches, and lucerne is due to some of these micro-organisms. The study of the organisms in the soil has revealed that one class of bacteria can change atmospheric nitrogen into combined nitrogen in a well-aerated soil with a sufficiency of lime. The organisms have been isolated and their manner of growth and reproduction studied. They are known as *Azotobacter*.

Another organism can fix the atmospheric nitrogen in a soil with less air, as in a waterlogged soil. This organism is less active. It is known as *Clostridium pasteurianum*.

There is a third class which enters the root hairs of clover and other leguminous plants. They cause the formation of nodules or enlarged growths on the roots. In these they grow and multiply, taking nourishment from the plant and at the same time converting the nitrogen from the air into nitrogen compounds in their bodies. Later they and the nitrogen are absorbed by the plant. Many of the roots and nodules remain and return to the soil, thus enriching it in nitrogen.

This kind of mutual arrangement between organism and plant is known as " symbiosis ".

These biological or bacterial processes were only understood after many years of experiment by different workers. Records of crop yields and of manures added were kept by a French scientific farmer named Boussingault who analysed the plants and the manures. He found that when clover or lucerne was grown the crop contained more nitrogen than that supplied by the manures and known to be present in the soil. Later it was found that sterilised or heated soil did not behave in the same way. Hence it was due to the living organisms present in the soil. Other experiments showed that plants gained as much nitrogen as that which was lost from the air.

Finally, the organism responsible was discovered and isolated. Its life history has been studied in detail. It is now known as the root organism or *Bacillus radicicola*. Some soils which did not allow lucerne to grow well have been successfully inoculated with this organism and crops of lucerne obtained. A knowledge of these bacterial changes should be of use to the farmer.

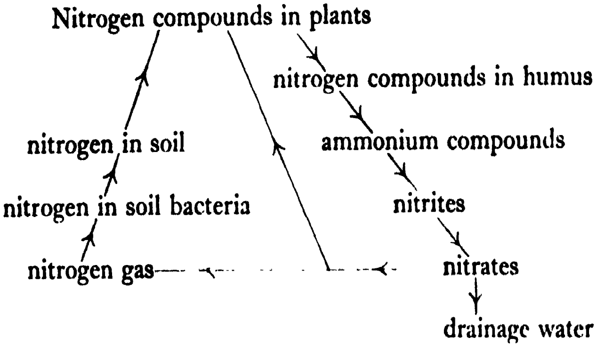
By cultivating the soil, by hoeing and working it, air is admitted. The humus is now decomposed or oxidised and the nitrogen changed by the nitrifying organisms to the readily available nitrate. This works best in a soil with sufficient moisture and not sour or acid; the process slows down in a dry or sour soil. The same conditions are necessary for the fixation of nitrogen by *Azotobacter* in the soil and by *Bacillus radicicola* in the roots of clover and other leguminous plants. The soil that has grown such plants has gained nitrogen, so a straw crop can follow a ley. The growing of a seed mixture or temporary ley during the rotation thus maintains the fertility of the soil.

Before leaving this subject we might consider whether these biological processes can be controlled. The soil can be sterilised by heat and by antiseptics and the organisms destroyed. Soils are only partially sterilised by such methods. The result is at first a great decrease in the number of the organisms present, followed later by an increase. This is accompanied by a great increase in the amount of ammonium compounds present and consequently an increase in the fertility. How can we account for these changes ? Soils which are heavily manured with farmyard manure, as in market gardens and greenhouses, may after a time become sick. This sickness is removed or remedied by sterilising the soil by heat. There is evidence to show that larger organisms than bacteria, such as the protozoa, live on the bacteria. While heating the soil will destroy both the organisms, the bacteria that survive soon multiply with great rapidity. On the other hand, the effect of heating the soil will be to decompose some of the humus and so set free more nitrogen and thus increase the fertility.

It has already been stated that the nitrates produced are very soluble substances. In periods of heavy rainfall much of the nitrate is washed out. Some therefore consider the process of nitrate formation to be very undesirable. However, it is not possible to see at present how it can be prevented since it would necessitate the sterilisation of the soil on a very large scale.

The various changes that the nitrogen compounds undergo are shown in the arrangement below:

The Nitrogen Cycle


Nitrogen compounds in plants
nitrogen compounds in humus
ammonium compounds
nitrites
nitrates
drainage water
nitrogen in soil
nitrogen in soil bacteria
nitrogen gas

CHAPTER VII

THE REQUIREMENTS OF PLANTS: POTASSIUM

Potassium.—Humus is not the only source of plant food. The exceedingly small mineral particles in the soil contain many elements, among them being potassium, phosphorus, calcium, magnesium, iron, aluminium, and manganese. In this chapter we shall concern ourselves with the element potassium. Its compound with oxygen is well known to farmers under the name potash.

Potash and soda are the most alkaline compounds that are found in plants and in the soil. The proportion of potash greatly exceeds that of soda in most plants.

In the ash of plants grown at Rothamsted the proportions of potash and soda were—

	Potash, per cent	Soda, per cent
Wheat grain .	33·12	0·15
Wheat straw .	13·50	0·10
Barley grain .	27·20	2·70
Barley straw .	12·72	10·22
Barley straw grown without potash	7·17	11·54
Potatoes . .	55·50	0·15

The percentages of potash and soda in the ash of mangels is especially interesting, as seen in the table at top of page 31.

The addition of soda reduces the proportion of potash in

Manuring	Soda, no Potash	Soda and Potash	No Soda, no Potash	Potash, no Soda
	%	%	%	%
Potash in ash .	12·83	29·09	17·83	40·55
Soda in ash .	37·01	23·05	19·54	9·69
Lime in ash .	5·53	5·63	16·29	7·88

the mangels and the response of the mangels to both soda and potash is very marked. When potash and soda are omitted the mangels take up a much larger amount of lime, and more lime is taken up when soda is omitted than when potash is left out.

Only in the ash of barley straw and the ash of mangels does the soda exceed the potash. In potatoes more than one-half the ash consists of potash. Referring again to the table in Chapter V, page 24, it will be seen that the potash requirements of plants are much greater than that of phosphoric acid or lime and often exceed that of nitrogen.

What the Plant does with the Potash.—In most farm crops the chief constituent is starch. The cereal grains are mainly packed with starch. Potatoes consist largely of starch. In other root crops sugar is the chief substance, as in the sugar beet and mangels. Potash plays an important part in the formation of sugars and starch, or carbohydrates as they are called. With the help of potash, sunlight, and the green colouring matter of the leaves these substances are made from the carbonic acid in the air. Without potash the process ceases. Hellriegel showed that the weight of barley grains was proportional to the amount of potash supplied. Hence, to pack the grains of wheat, oats, barley, and maize with starch, and to fill out the sugar beet and mangels, adequate supplies of potash are essential. A shortage leads to unhealthy plant cells, delayed maturity, and to plant diseases. As an example, it has been shown that " leaf scorch " in fruit trees is due to lack of potash.

Potash in the Soil.—We have already learned that one of the most abundant minerals in the soil is orthoclase felspar, a constituent of granite. This is a potash-containing mineral which changes to kaolin or china clay when it loses its potash by weathering. In most British soils the total amount of potash in the soil is very large, especially in clay soils, since such soils will contain much partly decomposed felspar. Thus two Scottish soils reported by Stewart had 2·51 per cent and 1·22 per cent respectively, amounts equivalent to 25 tons and 12 tons per acre, or sufficient to last more than a hundred years. The minerals in the soil, however, yield up the potash very slowly. Of recent years, by the use of X-rays, the architecture of these minerals is slowly being revealed. They are complex arrangements of many silicon atoms with other atoms of aluminium, oxygen, potassium, calcium, and magnesium. It would appear that some of the potassium atoms can be replaced fairly readily by sodium atoms and so made available or more easily attacked by carbonic acid in the soil produced by the decomposition of the humus. This process of solution is a very gradual one, and, as in the case of the breakdown of humus, may be too slow to supply the needs of crops which require much potash.

The soil may supply the needs of a cereal crop but not a root crop, which therefore requires the addition of a quick-acting potash fertiliser. How does the plant take in its potash supply ? The roots of the plant are in intimate contact with the tiny soil particles ; these particles have a wet film around them, and in this film the potash is brought into solution by the carbonic acid ; this film with its potash and other soluble substances is sucked into the plant. How then can we find whether a soil has sufficient available potash ? We must confess we have no real answer to this question. The root system of each crop varies considerably. All that can be done is to give an approximate answer as a guide to manuring for a particular crop. The farmer can usually answer the question himself better than anyone else, from his knowledge of the crops grown on his own particular soil.

When the root crop is good there will be no lack of potash. Of course, farmers usually ensure this by adequate manuring with farmyard manure and potash fertilisers. What the chemist tries to do is to imitate the action of the soil water on the soil particles. He therefore shakes a known weight of the soil with a certain quantity of a weak acid solution and determines how much potash has been made soluble or available. If he always carries out the test in the same way, he will be able to compare the soils in his district as to the rapidity with which they give up their potash. At the present time a chemist in one region will use one method while another in a different region uses another method. It was mentioned that some of the potash may be easily replaced from the mineral structure. This is the basis of another method for determining available potash by leaching it out or washing it out with a salt solution. The potash so removed is known as exchangeable potash.

Yet another method which was much used in Germany was to grow 100 rye seedlings in 100 parts of soil mixed with sand and supplied with water. After 17 days the plants are uprooted, dried, weighed, and the amount of potash taken up determined. Such plants may absorb from 4 to 50 milligrams of potash in this way. The soil was considered well supplied if 24 milligrams were absorbed. Potash so taken up is known as root-soluble potash.

Stewart obtained the following figures for two Scottish soils :

	Total Potash	Acid-soluble Potash	Citric-soluble Potash	Exchange-able Potash	Root-soluble Potash
	%	%	%	%	%
A	2·51	0·742	0·0102	0·0195	0·0129
B	1·22	0·213	0·0025	0·0051	—

The acid-soluble potash was extracted with concentrated hydrochloric acid : the citric-soluble potash with 1 per cent citric acid. The latter test is much used in this country and soils which have 0·01 per cent citric-soluble or less will usually show the need for fertilising with potash manures, as in the case of soil B above. Since it is generally conceded that extraction with any weak acid will give much the same information, it would be an advantage if some standard method were now agreed upon so that all results could be correlated and studied. Much of the information is now obscure if not altogether useless.

Potash from Humus.—Since the humus is found from decayed vegetable matter, and as we have learned that plants take in potash, it follows that the humus also contains potash. As in the case of nitrogen the potash becomes soluble or available very gradually.

Is Potash lost from the Soil ?—We have already considered the quantities of potash removed by crops. All the evidence obtained by analysis of the drainage water from soil and by drawing up a balance-sheet showing amounts in the soil, added-in manures, and removed by crops, goes to prove that the soil has a remarkable power of retaining potash. This is well seen in the figures obtained by analysis of the water from the Aberdeen drain gauges — all the potash added to the soil was retained. This property of fixing potash is possessed mainly by the finest clay and humus soil colloids, to which reference was made in Chapter III.

CHAPTER VIII

THE REQUIREMENTS OF PLANTS: PHOSPHORUS

Phosphorus.—The minerals in the soil which contain phosphorus are few in number. They are of animal origin. The greatest source of phosphorus is to be found in bones. For centuries animals and human beings have been buried in the earth and their remains gradually become intermingled with the soil particles. The humus, too, will contain phosphorus but the greater proportion will be present in the mineral matter. The quantity of phosphorus actually present will be relatively small. For the reasons stated above, British soils have a phosphorus content on the average from 0·1 to 0·2 per cent, which is equivalent to one to two tons per acre. Soils from South Africa and parts of New Zealand have much less, with the result that crops are deficient in phosphorus and there is a lack of bone-forming material for the animals.

Phosphorus and the Plant.—A supply of phosphorus in a soluble or available form enables the young plant to develop a more extensive root system, especially the small fibrous roots. It is a great advantage to the plant in the early stages of growth. The plants or crops reach maturity more rapidly, so an earlier harvest follows adequate phosphorus supplies. As the plant grows the phosphorus passes into the flower and eventually into the seed. Since phosphorus plays a part in every cell of the human and animal body, its presence in foods for human beings and animals is essential.

Phosphorus in the Soil.—In the soil the phosphorus exists combined with the basic elements calcium, magnesium, iron, and aluminium in the form of phosphates of these elements. Of these the phosphates of calcium are more soluble in weak acids, while the phosphate of iron is almost insoluble. Soils, therefore, that are acid or deficient in lime will contain the less available phosphates of iron and aluminium. The effect of maintaining sufficient lime in the soil is now seen to be of advantage in providing available phosphate. This fact will also assist the growth and multiplication of bacteria. As in the case of potash, the amount of phosphorus taken up by the plant will depend on its root system, and this varies with the species of the plant. The carbonic acid in the soil water brings the phosphate of lime into a soluble form and this is sucked up by the roots. By treating the soil with a weak acid solution in the same way as extracting the potash, chemists endeavour to find whether the phosphate in a particular soil will become soluble fast enough to feed the plant.

The quantity of phosphorus calculated as phosphoric acid (P_2O_5) extracted from a known weight of soil by a solution of the acid employed is determined. The actual methods employed vary in different districts.

The method of growing rye seedlings in soil and sand is also used to find the root-soluble phosphate. If a 1 per cent solution of citric acid is used as the extracting agent, those soils which show a content of citric-soluble phosphate less than 0·01 per cent will generally be found to respond to phosphatic fertilisers; that is, they will give increased yields when phosphatic fertilisers are applied. The quantities of phosphoric acid taken up by average crops of various kinds are given in the table on page 24.

It will be seen that most crops take up much less phosphoric acid during growth than they do of potash or nitrogen. Notwithstanding this, most compound fertilisers contain much more phosphoric acid, usually in the form of superphosphate, than they do of potash or nitrogen. The purpose of this is to give the plant a good start with readily available phosphate.

Is Phosphorus lost from the Soil?—Analysis of drainage waters from soils and drain gauges reveals that practically no loss of phosphorus occurs in this way. The compounds of phosphorus formed in the soil or added to it as fertilisers become insoluble. Phosphates of lime slowly dissolve in the soil water and nourish the plant. The phosphates of iron and aluminium are much less soluble. The soil has in fact a remarkable power of fixing phosphoric acid and potash so that practically none of these is washed out by rain. In applying superphosphate or potash fertilisers this fixing power of the soil should be remembered.

The Phosphorus Cycle.—The phosphorus in the soil passes into the plant and from the plant to the animal. Most of it is excreted in the dung but some of it will be retained and utilised for the formation of bone. When the animal is killed the bones are converted into bone meal and returned to the soil.

CHAPTER IX

THE REQUIREMENTS OF PLANTS: CALCIUM

Calcium.—Calcium is a metallic element which when combined with oxygen forms the substance known as quicklime or burnt lime, CaO. This substance is usually obtained by burning limestone, the carbonate of calcium, with coke in a lime-kiln. The carbon dioxide, CO_2, is removed as a gas, leaving lumps of burnt lime. When water is added to this burnt lime it soon becomes very hot, clouds of steam escape, and the lumps fall to a fine bulky power known as slaked or hydrated lime. This is a compound of quicklime and water, $Ca(OH)_2$.

These three forms of lime, the oxide, the carbonate, and the hydrate, are not very soluble in water. The carbonate will, however, dissolve in water containing carbon dioxide. Since the water in the soil always contains some of this gas in solution, it will dissolve some of the calcium carbonate in the soil, and consequently some of the lime in the soil may be lost in the form of soluble bicarbonate.

It has already been mentioned that the very soluble nitrate of lime is produced by the decay of humus and that this may pass out of the soil also into the drainage water. Fertilisers like sulphate of ammonia displace the calcium held by the clay and humus by a process known as " basic exchange ". The result of all these processes is that more calcium is lost from the soil than any other element. It may be said that the principal base or antacid substance is removed in this way.

These calcium compounds, burnt lime, slaked lime, and carbonate of lime, or the oxide, hydrate, and carbonate, are basic or antacid substances. They are able to neutralise the acidity of soils. The fertiliser known as superphosphate of lime is different. It is not basic but is in reality acid, being partly neutralised phosphoric acid. It is therefore capable of fixing or combining with the lime in the soil, forming a phosphate which is slowly soluble in the soil water. Superphosphate also contains sulphate of calcium and this also is not basic, so cannot remove acidity. The application of superphosphate does, however, to some extent minimise the removal of lime from the soil. It is of great importance to understand the changes that lime undergoes when applied to the soil as well as the changes brought about in the soil itself. As a rule burnt lime is placed in heaps and allowed to slake or become hydrated by the rain or the water vapour in the air. The fine powder is then spread over the land and should be thoroughly incorporated or mixed with the soil.

Ground quicklime is applied by means of a distributor. The soil where the heaps have been deposited will have been heated and thus be partially sterilised ; insects, slugs, and bacteria will have been destroyed. After distribution the lime will soon go back to the original carbonate form by combining with the carbon dioxide in the soil. It will no longer be caustic or burning. In this form it will serve several purposes. Some of it will neutralise any acids formed from the humus. Some of it will be converted to the very soluble nitrate of lime by combining with the nitric acid formed by the decomposition of the humus. This may go into the crop or be washed out. Some of it may form the soluble bicarbonate by dissolving in the soil water. Some of it may react with the iron and aluminium phosphates and slowly change them to the more soluble and more available phosphate of lime, at the same time preventing a loss of lime. Some of it may become absorbed by the fine clay particles or by the humus, at the same time replacing or turning from the clay or humus, equivalent amounts of other basic elements such as sodium or magnesium or acid hydrogen. Potassium is not replaced by lime in this manner unless very large amounts of lime are applied. This phenomenon known as " basic exchange " is of very great significance, since it alters in a remarkable manner the character of the clay and humus and therefore of the soil.

The difference in texture of a clay soil which has been limed and the same soil left untreated can often be felt by walking over it. The minute particles of the clay have become flocculated or collected together to form larger particles or crumbs, thus improving the drainage and removing surplus water and at the same time admitting air. This in turn facilitates oxidation and the decay of humus with the production of nitrates. The growth and multiplication of bacteria is also helped. In short, the soil gives up its fertility by increasing the loss of humus ; while overliming may fix the carbon dioxide in the soil, and thus prevent it attacking the phosphate and potash compounds in the soil as well as making the iron, manganese, and boron compounds unavailable. It thus follows that a slight acidity of the soil is an advantage. This question will be considered in the next chapter.

Calcium as a Plant Food.—There is evidence to show that a deficiency of calcium in the soil leads to stunting of the root and to discoloration of both roots and leaves. The plant will contain a smaller amount of calcium than one grown where the calcium supply is adequate. Since calcium is one of the chief constituents of bones, it is of the utmost importance in human and animal nutrition. In the case of animals the main source of calcium supply will be that provided by grass, hay, and kale. Malnutrition of animals due to deficiency in the calcium supply has been of frequent occurrence. It has been found that there is great variation in the calcium content of pasture grass from different districts. To remedy this it has become the practice to give farm animals supplementary minerals in the form of ground chalk or finely ground phosphate of lime such as steamed bone flour. Pig breeders have obtained remarkable results with farrowing sows by adding such supplements to the rations.

From these facts it would follow that it is a matter of the greatest importance to maintain in the soil a sufficiency of calcium for the plant and ultimately for the animal. It will be seen from the table on page 24 that the intake of calcium by many crops is surprisingly small. The cereal crops remove only about 10 lb. per acre and potatoes only 3 lb. The root crops and hay remove from 50 to 90 lb., while broccoli and brussels sprouts make heavier demands and remove from 100 to 150 lb. per acre.

It will be realised, therefore, that the supply of calcium for feeding the plant will usually be sufficient but there may not be enough for keeping the soil in proper condition. It must also be noted that there are various compounds of calcium present. In well-limed soils there will be free calcium carbonate and the humus and clay particles will possess sufficient calcium in the exchangeable or available form.

Other soils may have a good percentage of this absorbed calcium yet still be slightly acid and capable of producing good crops ; while others may be more acid and have a low value for absorbed or exchangeable calcium. These will be improved by liming. Practically all soils contain some calcium phosphate, the main source of the phosphorus supply for the plant. All soils contain calcium silicate in the mineral or rock particles. From this compound the calcium will not be readily released.

We have learned in this chapter that the soil contains various compounds of calcium, some of which are readily soluble or available while others are not. The least available is the silicate and the most available is the carbonate. The clay and humus particles hold calcium in such a way that it is readily given up in exchange for another basic element such as potassium or sodium. Another calcium compound, namely calcium nitrate, is formed from the nitrogen in the humus. This compound is very soluble and so may pass into the drainage water. Some calcium sulphate may also be lost in this way. Lastly, soils contain calcium phosphate.

Base Exchange.—If some soil is placed in a funnel and a solution of common salt poured on it, the liquid passing through the soil will be found to contain compounds of calcium or lime compounds. The element sodium in the salt, that is sodium chloride, has turned out the calcium in the soil. This exchange is practically instantaneous and it proves that the calcium in the soil must have been present in such a condition as to be easily exchanged. Other loosely held or exchangeable basic substances are also released, namely potassium and magnesium. This phenomenon is known as basic exchange.

The predominant base in most soils is calcium, so this is released in greatest amount and at the same time lesser quantities of other bases. The amounts released are in proportion to the chemical equivalents or combining weights of the elements; thus 23 parts by weight of sodium will release 20 parts by weight of calcium. These exchangeable bases are held by the colloidal clay and humus particles in the soil ; they serve to neutralise the acidic character of these substances. They are released by salts other than sodium chloride. The various soluble salts used as fertilisers all bring about exchange of bases. The sodium in nitrate of soda, the ammonium in sulphate of ammonia, the potassium in nitrate, muriate, and sulphate of potash, the calcium in sulphate of calcium which is present in considerable amounts in superphosphate, and the magnesium salts in kainit and potash salts — all these release bases from the soil.

In reclaiming land from the sea, the salt which gave sodium to the soil colloids must be removed and also the sodium in the colloidal particles. The sodium must be replaced by calcium and a sodium clay transformed into a calcium clay, in order to bring into being a fertile soil. A portion of the sea is enclosed by dykes, the water pumped out, and the land left to the action of the rain. Gradually the sodium is washed to the lower depths of the soil and the calcium in the silt or soil particles predominates, thus a calcium clay is formed. On this, vegetation soon begins to grow, the land dries and becomes fertile. This same principle of basic exchange is utilised in the softening of water by treatment with certain complex sodium silicates. In this case the exchange is the reverse of that which occurs in soils. The sodium in the silicate is replaced by the calcium or lime in the hard water. After a time the silicate is saturated with calcium and so becomes ineffective. It is made active again or regenerated by treatment with salt when the sodium replaces the calcium in the silicate.

By the application of fertilisers and also by the acids from the humus the calcium may be removed to such an extent that the soil becomes very acid. Unless this is corrected by liming, the acidity may exceed the critical value for many crops. This will be considered in the next chapter.

CHAPTER X

SOIL ACIDITY

IN order to understand this important problem we must first consider the electrical properties of water. Water is an exceedingly poor conductor of electricity. If a little salt is added to the water, it becomes a good conductor. Why is this ? When the salt dissolves in water it furnishes positively charged sodium particles or atoms and negatively charged chlorine atoms. These carry the electric current ; the former travel to the negatively charged plate connected to a battery and the latter to the positively charged plate or electrode when these are inserted in the solution. In water there are positively charged atoms of hydrogen and negatively charged coupled atoms of hydrogen and oxygen or hydroxyl (OH). These charged atoms or groups of atoms are called ions. They are the carriers of electricity. The very poor conductivity of water is due to the fact that the number of ions or carriers is exceedingly small. In solutions of acids, bases, and salts they are very numerous.

It is calculated that the quantity of hydrogen ions in a litre of water is only 1/10000000 gm. This fact is usually stated as follows : The concentration of the hydrogen ions in water is $1/10^7$ or 10^{-7}, that is, the intensity of the acidity of water is measured by the figure 7 indicating a ten-millionth part of a gram of hydrogen ions. The seven represents the power of the acid hydrogen and is the number of noughts in the denominator of the fraction representing

The symbol *p*H is used to denote acidity in this way. In this case the *p*H or power of the hydrogen is 2. The acidity of water or the *p*H of a neutral liquid is 7. The scale of acidity thus increases in intensity from 7 downwards.

A solution with 1/10 gm. of hydrogen ions has a *p*H of 1
„ „ 1/100 gm. „ „ „ „ 2
„ „ 1/1000 gm. „ „ „ „ 3
„ „ $1/10^7$ gm. „ „ „ „ 7

This scale of measuring acidity serves only for concentrations of acid which are less than 1 gram of hydrogen ions per litre.

The Measurement of the *p*H or Intensity of the Acidity.—There are certain coloured substances which give definite colours depending on the intensity of the acidity; there is a fairly distinct colour for each value of the *p*H. If a sample of the soil is shaken with water and one of these substances added, the colour will indicate the *p*H or intensity of the acidity, and from that an idea or rough estimate of the lime requirement can be made. In earlier days litmus was used as the colour indicator but nowadays a wide range of indicators is available.

Soil Acidity.—The intensity of the soil acidity varies with different soils. Chalky soils are rarely acid but usually alkaline with a *p*H of 8, but most arable soils are on the acid side with a *p*H varying from 3 in extreme cases as on peats and on soils derived from the granite, to a *p*H of 5 or 6 for most soils. Garden soils are so frequently treated with lime that in most cases they are alkaline.

Crops and Acidity.—Farm crops can tolerate a certain amount of acidity. The degree of acidity that each crop can approximately withstand has been determined and is shown in the table below :

Red clover	5·5	Wild white clover	4·5
Sugar beet	5·3	Rye grass	4·3
Mangels and barley	5·2	Oats and rye	4·2
Wheat	5·1	Potatoes	4·0
Swedes, turnips, etc.	4·9		

It will be seen that red clover is least able to withstand acidity while potatoes can grow satisfactorily on a fairly acid soil.

In addition to the use of coloured indicators for determining the acidity of soils there are now available electrical methods for this purpose which enable this determination to be carried out with accuracy and precision.

The Relationship between Soil Acidity and Exchangeable Calcium.—As would be expected, soils which are only slightly acid, having a *p*H of, let us say, 6 or more, are found to possess a high percentage of available or exchangeable calcium, and soils which are markedly acid have a low value for that element. In the former the clay and humus particles have absorbed the calcium from the lime in the soil, while in the latter they have lost the calcium and in its place acid hydrogen ions have entered.

The Determination of the Lime Requirement of a Soil.—An estimate of the lime necessary for the correction of acidity can be made in the following ways :

1. From the measurement of the *p*H or intensity of acidity.
2. From the estimation of the exchangeable or available calcium present.
3. From the determination of the amount of lime that will be taken by a definite weight of soil from a solution containing a known quantity of lime.

From all this information it can be concluded that the problem of acidity and need for lime can be satisfactorily solved.

Can a Soil be Over-limed ?—Certain constituents of the soil are rendered insoluble or unavailable if too much lime is applied. Such constituents are boron, manganese, and iron. We shall return to these elements in a later chapter. The relationship between the acidity as given by the *p*H figure and the amount of lime required to remove that acidity is given in Table I.

In Table II the relationship between the available lime or exchangeable lime and the amount of lime required is seen.

These figures must not be taken as applying to all soils in all circumstances but rather as guides to the amounts required.

[*See tables on facing page —*

TABLE I

AMOUNTS OF LIME REQUIRED TO CORRECT ACIDITY MEASURED BY *p*H

Cwts. of Lime (CaO) acquired per Acre

*p*H	Light Sand	Loamy Sand	Light Loam	Loam	Clay	Silts
4·0	100	105	115	120	135	155
4·2	90	95	105	110	130	145
4·4	85	90	95	100	120	130
4·6	75	80	85	90	110	115
4·8	65	70	75	80	100	100
5·0	55	60	70	75	90	90
5·2	50	55	60	65	80	75
5·4	40	45	50	55	70	60
5·6	30	35	40	50	60	45
5·8	20	30	35	40	50	30
6·0	10	20	25	30	40	15

TABLE II

RELATION BETWEEN AVAILABLE LIME AND AMOUNT OF LIME REQUIRED

Cwts. of Lime (CaO) required

Available Lime %	Sands and Loams	Clays	Available Lime %	Sands and Loams	Clays
0·00	60	70	0·18	14	34
0·02	56	66	0·20	20	30
0·04	52	62	0·22	16	26
0·06	48	58	0·24	12	22
0·08	44	54	0·26	8	18
0·10	40	50	0·28	4	14
0·12	36	46	0·30	0	10
0·14	32	42	0·32	0	6
0·16	28	38	0·34	0	2

CHAPTER XI

ELEMENTS OF LESSER IMPORTANCE

THERE are a number of mineral elements present in the soil, which are taken up by plants, that will now be considered. Among them are magnesium, iron, aluminium, manganese, boron, copper, zinc, cobalt, iodine, chlorine, and silicon.

Magnesium.—The properties of this element closely resemble those of calcium. The requirements of plants for magnesium are small. This can be seen from the table on page 24. Cereals remove about 10 lb. per acre. Clover requires about double the quantity, and mangels about four times the amount. Most soils contain about one ton of magnesium per acre. As in the case of calcium, the element is present in different states of combination. Some of it, possibly most of it, is combined in the complex silicates in an unavailable state; some of it in the exchangeable form readily replaceable by other bases; the amount in this form varies in different soils and is often only one-tenth the amount of the exchangeable calcium.

When the exchangeable calcium in clay soils is replaced by magnesium, the soil texture becomes like that of sodium clays. The clay is readily deflocculated or puddled and therefore deteriorated. In the plant itself magnesium is an essential constituent of the green colouring matter of the leaf or chlorophyll, so the effect of magnesium deficiency will be seen in the condition of the leaves, which become discoloured or spotted and often fall off prematurely. Eventually the magnesium moves to the seed. It is believed to be necessary for the formation of oil in the plant. Excess of magnesium salts will produce harmful effects on soil and plant.

The commonest compound of magnesium is magnesium sulphate or Epsom salts. Soluble magnesium compounds are always present in the potash fertilisers, kainit, and potash salts.

Iron.—Most soils contain an abundance of iron. The iron compounds are mostly insoluble and little passes into the plant. If excess of lime is applied to the soil, the iron compounds become still less soluble and the plants become discoloured or chlorotic. The iron mostly passes to the leaves in a normal plant and gives them a dark-green colour. In the subsoil the less oxidised form of iron compounds are often present. These are called ferrous compounds. They are toxic to plants. This is one of the reasons why the subsoil should not be dug up and mixed with the top or well-oxidised soil. Some of the iron in soils will exist in the form of iron phosphates. It is interesting to note that the ferric phosphate is practically insoluble and therefore unavailable to plants, while the ferrous or less oxidised form is readily soluble.

The greater part of the iron in soils is present in the form of the red oxide or hydroxide, and is often referred to as the sesquioxide. It is practically the same as ordinary rust. The red, yellow, and brown soils owe their colour largely to this iron oxide. It can be dissolved by acids. These may in some soils be formed from the humus. In this way the iron oxide may be removed from the surface soil and carried to lower depths. Here it may be deposited again and form an iron pan. The formation of this pan is also in part due to the peculiar colloidal properties of iron hydroxide. This means that it can be brought into a highly dispersed condition or deflocculated state or into a coagulated or flocculated state.

In acid soils the iron compounds are partly soluble and such soils give a red colour to an alcoholic solution of potassium thiocyanate. This is the basis of the Comber test for acidity in soils.

A deficiency of iron in the food of animals is known to be the cause of disease, particularly anaemia. The importance of feeding green food which contains the iron compounds as well as vitamins will therefore be appreciated.

Aluminium.—As in the case of iron, most soils contain an abundance of aluminium. The oxide of this element is both basic and acidic. With silica it forms complex aluminosilicic acids or clay acids. The silicates in the soil are mainly compounds of these acids with the bases lime, potash, magnesia, and soda. In acid soils alumina acts as an exchangeable base. When the acidity is sufficiently great, soluble aluminium salts are formed. These are believed to be toxic to plants. In normal soils little aluminium will be in the soluble condition. In such quantities its effect on plants is not very marked although it is believed to be an essential element.

Silicon.—It has been mentioned several times that this element is one of the principal constituents of rocks and that it is the most abundant element in the soil. It is taken up by cereals and grasses in greater quantities than lime and magnesia. Notwithstanding this fact, it is not regarded as an essential element in plant growth.

Chlorine.—The chief source of this element is common salt or sodium chloride. Small amounts are taken up by plants, usually about 10 lb. per acre. Such crops as mangels, sugar beet, lucerne, and grasses remove larger quantities. It is harmful in large doses. In coastal districts the salt spray is brought down by the rain and the soil gains considerable amounts of salt. Even inland appreciable quantities may come into the soil from this source. Chlorine is also supplied in kainit and potash salts. A deficiency in chlorine in the soil or in the crop is therefore unlikely to occur.

Iodine.—This is considered an essential element. Minute amounts are found in plants. Addition of soluble iodides to the soil does not result in increased crops. A deficiency of iodine in the food of livestock is associated with certain diseases just as it is with goitre in human beings. Iodine is present in the leaves of plants, so the importance of green food is again emphasised.

Sulphur.—This element is essential for plants. Only small quantities are removed from the soil per acre. Sulphur is a constituent element of many of the common fertilisers such as sulphate of ammonia, superphosphate, basic slag, sulphate of potash. As a rule there is an adequate supply in the soil. It is required for the production of the particular sulphur-containing compound known as cystine in plants. There is a large percentage of this substance in the wool of sheep. Cabbages and swedes contain fair quantities of sulphur compounds.

Manganese.—This is found in small quantities in all plants. It is essential for their full development. In its absence the leaves become diseased and are seen to be spotted or chlorotic. When soluble manganese salts are added to such plants the healthy green colour is restored and the yield increased. Only one or two pounds per acre are necessary since excessive amounts are injurious. This diseased condition has been reported in the case of oats, spinach, lettuce, beet, and maize. As in the case of iron, excess of lime makes the manganese compounds in the soil insoluble and unavailable.

Boron.—This element is present in boric acid and in borax. It was shown at Rothamsted that broad beans grown in a culture solution failed to develop fully unless boron was supplied. The amount added was only one part of boric acid per million parts of solution. More than one part in five thousand was harmful. It affects the development of nodules on the roots. Later it was shown that certain diseases of plants could be cured by small dressings of borax. Heart rot in sugar beet, brown heart in swedes, internal cork in apples are curable by such treatment. If supplied in anything but small quantities borax is harmful. In this case also, excessive liming renders the boron compounds in the soil insoluble and unavailable.

Copper.—Very small quantities of copper are found in all plants. Only on soils that are rich in organic matter have applications of copper sulphate or blue stone been shown to effect improvement. Market garden crops and oats have given increased yields when 50 lb. per acre of copper sulphate were applied.

Zinc.—In water cultures zinc salts have been found to be essential to the growth of several plants. Certain diseases of fruit trees in America have been remedied by the application of zinc sulphate.

Cobalt.—In recent years this element has been given prominence because certain animal diseases have been attributed to a deficiency of cobalt in the food. This element is always present in minute traces in plants, and in the soil. Cases have been reported of cobalt deficiency in soils in England and the question is under investigation.

CHAPTER XII

SOIL ANALYSIS

The student will have learned from the preceding chapters that nearly all soils contain an abundance of the elements required for plant growth. The farmer or market gardener is able to see from the appearance and yield of the crop whether it is satisfactory or otherwise. Only on rare occasions should it be necessary to seek expert advice on the question of manuring.

What are the questions that are likely to present themselves? Among them will be the following: Has the soil enough lime? Can the crop obtain sufficient nitrogen, potash, and phosphoric acid? Why has a particular crop failed or given a poor yield? He can often find the answer to the last question since it is frequently due to other causes than improper or insufficient manuring. The soil may be improperly drained, or, on the other hand, too easily drained and liable to drought. It may also be due to insect pests or to some kind of fungus. Leaving out these causes, it may be stated that the most common cause of infertility is acidity or sourness. This has already been discussed, and from the various methods considered it was concluded that on this problem the soil chemist can give satisfactory and valuable information.

Lack of nitrogen will be shown by the poor growth and general appearance of the plant. This is quickly remedied by the application of small quantities of a nitrogenous fertiliser such as sulphate of ammonia. Quantities like 1 cwt.

per acre, or ¼ to ½ oz. per square yard, are usually sufficient

Little information can be given by the soil chemist concerning the availability of the nitrogen in the soil, since this depends on the activity of the bacteria which decompose the humus.

The Availability of the Potash and Phosphoric Acid.—To understand the problem that confronts the chemist, let us consider the rate of intake of potash by a crop of mangels. It will be seen from the table on page 24 that this crop removes about 300 lb. of potash per acre during its period of growth. Little of this is taken in during the early stages; most of it is absorbed during the warm summer months. Let us assume it is all taken in during the three months of July, August, and September. The crop absorbs 300 lb. of potash in 91 days. We will also assume that it comes entirely from the soil, so that 1 acre of soil, or 1000 tons of soil, yield 300 lb. of potash in 91 days, or 3⅓ lb. per day. So 1 ton of soil would yield 0·00333 lb. per day, and 1 lb. of soil would yield only 0·7 milligram.

The chemist usually works with quantities of about ¼ lb. or less and extracts the potash in a few hours, and all the methods of chemical analysis which he employs extracts the potash much faster than the speed with which the soil yields up its potash to the plant. In other words, the intake of potash by the plant is slower than any of the methods of chemical analysis so far devised.

Our calculation shows that 1 lb. of soil would yield less than 1 milligram of potash in 24 hours.

On the Continent the growing plant is used to find whether the soil will give up potash fast enough for satisfactory growth. Some experimental stations, mostly in Germany, grow 100 rye seeds in a mixture of soil and sand for 17 days. The seedlings are then uprooted, dried, burned to ash, and determinations made of the quantities of phosphoric acid and potash extracted from the soil.

This method, known as Neubauer's, is carried out as follows: 100 gm. of the soil are mixed with 50 gm. of fine sand in a glass basin. On the top of this are placed 250 gm. of fine sand moistened with water. In this are planted 100 rye seeds, previously weighed and treated with a disinfecting solution. After 17 days the seedlings are about 6 inches in height. They are then uprooted, and the potash and phosphoric acid extracted by the roots are determined. In the 17 days the seedlings may take up from 5 to 50 mgm. of potash. From a good soil it is stated that 24 mgm. of potash should be taken up and about 6 mgm. of phosphoric acid. These quantities are equivalent to 0·024 per cent of root-soluble potash, and 0·006 per cent root-soluble phosphoric acid. This is equivalent to 31 lb. of potash per day from an acre of soil, and is evidently enormously faster than that given up by the soil to crops in the field.

The method can serve to indicate soils in which the available potash may be described as high, medium, or low.

Another method, known as the Mitcherlich method, also makes use of the growing plant. Oats are grown in pots. One pot contains soil and sand only; three other pots contain the same weights of soil and sand, but to these are added a sufficient amount of a complete fertiliser containing nitrogen, potash, and phosphoric acid. Another three pots contain soil and sand as before and the same amounts of nitrogen and phosphoric acid, but no potash. Yet another three pots contain sand and soil and the same amounts of nitrogen and potash, but no phosphoric acid. The same number of oat plants are grown in each pot and allowed to grow to maturity. The weight of each crop when dried is then determined. From the weights in the pots with and without potash the potash requirement of the soil is calculated. In a similar manner from the weights with and without phosphoric acid the amount of phosphoric acid is judged. The method actually used involves rather intricate calculations.

Both Neubauer's and Mitcherlich's methods have been subjected to considerable criticism, yet many thousands of trials on the Continent were carried out at a large number of experimental stations erected for the purpose. These trials were financed partly by Government aid and partly by the farmers themselves.

A third method, again widely used on the Continent and to some extent in this country, consists in growing a mould named *Aspergillus niger* on the soil. This mould commonly grows on damp and decaying vegetable matter. It is grown on the soil for a certain period of time, then collected, dried, and weighed. From the weight obtained the availability of the potash in the soil is determined.

The reader will now be asking himself why the farmer cannot find out for himself, from the yields of his crops, whether potash or phosphoric acid or both are required instead of asking a soil expert to grow plants for that purpose. The answer is that it is practically impossible to draw accurate and reliable conclusions from a single crop yield. So many factors are involved, such as seasonal changes, hours of sunshine, and variation in the soil in different parts of the same field. To minimise the errors a large number of replications or repetitions must be carried out. Conclusions drawn from a single plot or trial on the effect of a fertiliser would be useless, but conclusions from a number would be valuable since it is possible to ascertain the error involved in the experiment.

In this country the soil chemist has attacked the problem in a different manner. He does not grow plants in the soil but extracts the potash and phosphoric acid by shaking a known weight of the soil with a definite quantity of a dilute solution of a weak acid, or with a buffered solution of known acidity, of intensity about *p*H 4·5, that is the acidity of a fairly acid soil.

The amount of potash and phosphoric acid thus extracted will in all cases be much greater than the quantities extracted by plants from the soil, since each particle of the soil is brought into intimate contact with the extracting liquid. The amount extracted will also depend on the proportions of soil and acid solution and the period of contact or time of shaking, and also on the strength of the acid solution. The technique employed varies widely in the different regions and so far soil chemists have been unable to agree on any particular method. What might be suitable for one type of soil would be unsuitable for another type. The chemist is not a magician able to state exactly whether the roots of a certain crop will extract from a particular soil sufficient potash and phosphoric acid to give an abundant yield. More and more reliable field trials are required to supplement laboratory information before such answers can be given. These take time and involve considerable expenditure and much labour as well as patience and infinite care.

Sampling of Soil for Analysis.—It is not an easy matter to get a representative sample of soil from a field. In sampling industrial products, as for example basic slag, a portion would be taken from each bag and all the portions well mixed to obtain a sample for analysis. A field of 10 acres involves the sampling of 10,000 tons of soil. It is usual to take small samples from five or six places and mix them. The total quantity may be 10 lb. or 2 lb. If it is 10 lb. it represents only 1 part in 22,400. It may therefore happen that another sample taken later may show entirely different results. Evidently there is considerable room for standardisation and for a careful investigation of the value of the so-called soil analyses on which large sums of money are now spent. What he can and does do, is to compare the behaviour of a particular sample of soil when shaken with a weak acid solution with other soils of known fertility from the same region, and thus classify the available potash and phosphoric acid as high, medium, or low.

With the change-over during the war from grass to arable farming, and the cultivation of waste land, there came a demand for the examination of thousands of samples of soil and more rapid methods had to be found. There was little difficulty in meeting the demand from the point of view of classifying the soil according to the rate at which it would give up phosphoric acid. Phosphoric acid is easily and accurately estimated in small quantities.

Soils might be classed as very high, high, medium, low, and very low, by the particular method employed. If the soil falls into the latter classes, the normal recommendation is to apply 4 cwts. of superphosphates, or, in other words, to incorporate 75 lb. of soluble phosphoric acid with 1000 tons of soil. On acid soils deficient in phosphoric acid, the recommendation would be to apply lime first and superphosphate at a later date, or alternatively to apply 5 cwts. of basic slag. Rapid methods of determining available potash are more difficult. The chemist has not yet found any simple method of estimating very small amounts of potash. As we have seen, only extremely small quantities are extracted when the soil is shaken for a short time with a weak acid solution. Instruments of greater precision are, however, now being employed and improvements worked out. Newer methods of diagnosing mineral deficiencies in plants are coming into use. A recent publication shows the particular colorations and effects on leaves due to deficiencies of various elements. A considerable amount of work has also been carried out on the effects of injections of salts of various metallic elements into the leaves and other parts of plants and trees.

To sum up, soil analysis, or rather soil testing generally, means examination for three things only : firstly, the need for lime ; secondly, the rate at which the soil supplies available potash ; and thirdly, the rate at which the soil supplies available phosphoric acid. In special cases infertility caused by poisons such as arsenic or lead or absence of elements other than nitrogen, potassium, phosphorus, or calcium is investigated.

CHAPTER XIII

THE CLASSIFICATION OF SOILS

In a previous chapter soils were classified according to the texture or size of the particles as sands, loams, and clays. If there was a considerable amount of organic matter they were peat soils, and those with a preponderance of calcium carbonate were chalk soils. Russian scientists have investigated the effect of climate on soils and the changes which take place in them over long periods of time. These changes will vary in different climates.

Soils exposed to the action of a heavy rainfall will be changed differently from soils in a region where there is little or no rain. Mention has already been made of the weathering effect of water containing carbon oxide on the soil minerals. Different minerals give rise to different soils. Some of the products of weathering will be leached or washed down by rain-water percolating into the soil.

The humus in the soil is black and oxides of iron are red or yellow, hence changes in these will cause changes in the colour of the soil as we proceed from the surface downwards. If we dig a hole three or four feet deep in the soil, we can examine the different coloured layers in the face of the soil thus exposed. Actually it is called the soil " profile " and the different layers are called " horizons ". At the top there is the " A " horizon, then the " B " horizon, and so on until the parent or original rock is reached. The appearance of the soil profile records the history of the soil and the effects of rain, air, and carbon oxide over long periods of time.

Where there is or has been bad drainage there is usually in parts a mottled or patchy appearance. Modern classification of soils is based on this method of examining soil profiles both visually and also by chemical analysis of the different horizons.

An interesting example of this method is found in the case of soils in a humid climate which are freely drained and contain little or no calcium carbonate to neutralise acidity. The humus is consequently acid. This acid dissolves or disperses the red oxide of iron which is carried downwards by the rain, which we have stated will percolate freely in this kind of soil. If there are no plants growing and no earthworms to bring the red oxide back again, it will later be coagulated and deposited at this lower depth, thus forming a coloured horizon. The soil profile will thus consist of a black layer of humus at the surface, a light layer immediately below which is ash grey due to loss of iron oxide, then a somewhat darker layer followed by a reddish or brown layer of deposited iron oxide. Such a soil is called *podsol.* In some cases the deposit of oxide of iron may be sufficient to form an impermeable layer or " pan " of oxide of iron, which may stop altogether the downward flow of water. Many soils exist in which the process of podsolisation is still going on.

Brown Earths.—These soils show no distinct horizons. They are formed as a result of cultivation. The soil is being continually mixed ; crops are being grown which bring up material from below while fertilisers and manure are being added to the surface. These brown earths are usually fairly well drained and not very acid. Earthworms are active, mixing organic matter from the surface and also bringing up material from the lower depths.

Humus and Peat Soils.—Soils containing a large amount of organic matter are humus soils. In some humus soils the basic substances may have been largely removed by leaching, with the result that the humus is very acid. This humus will be slow to decompose and may form a thick layer on top of the mineral soil. Soils derived from acid rocks like granite are often of this type. In other humus soils there may be more basic substances so that the soil is less acid and the humus decomposes more rapidly.

Soils in Desert Regions.—Soils formed in regions where there is no rainfall will differ markedly from the above types. Water coming up from below rather than rain descending from above will influence the nature of the profile. This water will bring up soluble salts and give rise to saline and alkaline soils called *solonchaks*. If the water does not come up, the soils will have little humus and often much calcium carbonate together with calcium sulphate and alkali salts. These are known as "chestnut and desert" soils. Between the very dry and the humid climates there are climates of moderate to low rainfall, unevenly distributed while the temperature is high. Under these conditions humus accumulates in the surface soil. There is little leaching, so the bases remain in the surface soil, which is consequently neutral. There is no movement of silica or sesquioxides. These soils are called *chernozems*. In this country the majority of the soils are brown earths but podsols and humus soils are frequently found.

CHAPTER XIV

CONCLUSION

THE few inches of soil which cover the surface of the globe have produced in the past sufficient and even abundant food for the thousands of millions of people who inherit the earth. The needs of an ever-increasing population have been met and must be met in the future. Some of the reasons why this is possible will have been understood from the preceding chapters. These few inches of soil have their own living population of insects, moulds, and bacteria. Mankind is learning how to control this population, and how to make the soil more fertile so that larger and better crops can be produced. Moreover, by plant breeding, different varieties of plants are being produced, varieties which yield more, or are better able to withstand diseases, or more rigorous weather conditions, or capable of ripening earlier.

As the years go on, mankind is being supplied with more and better life-giving and health-giving foods. The cultivation of the soil and the growing of plants is a long, continuous, never-ending fight against all the enemies that compete for the food that the plant contains.

The apple grower who wishes to produce clean healthy fruit must adopt a system of spraying not once only, but several times during the year. The number of enemies to the apple grower alone appears to be legion. Newer and better insecticides and fungicides are being produced; the armoury of the grower is being constantly improved, so enabling him to have greater control of pests and parasites.

A study of the soil reveals that it is like a bank in which the capital of mankind is invested. This capital may be blown away by the winds, leaving canyons and gullies instead of fertile fields, unless it is protected. In most places in this country such erosion is rare. Here the capital invested, or the plant food in the soil, can only be drawn with extreme slowness, so fertilisers are added to give quicker returns. In the main the soil serves as a root-hold for plants, and for retaining and supplying the water they require.

Although this small book deals with the soil from the standpoint of the chemist, it should be realised that the study of the soil requires a team of workers. There are problems for the biologist, the engineer, the geologist, and the physicist. Much further research is in progress on the nature of the fine particles, the structure of the clay, and the nature of humus. Bacteriologists, mycologists, and entomologists are busy with the investigation of bacteria, moulds, fungi, and insects in the soil. The mechanical problem is the constant turning-over, disintegration, and fragmentation of thousands of tons of soil — a thousand tons for every acre — and its effect on yield.

With more mechanical power becoming available, already the question has been raised whether ploughing is the most efficient process. What is certain is that more mechanical power means more tillage and greatly increased crop production.

What differences there are in the crop yield in different parts of the country and often in the same part ! One farm will produce 7 tons of potatoes per acre, while another will produce 20 tons. All the reasons for these variations are not known, and many factors are involved. Different cultivation, different manuring, different rainfall, more hours of sunshine, more sunshine on the plots are but a few.

The facts recorded in this volume may enable the man or woman who cultivates the soil to have a greater interest in the work, and to keep the soil fertile. For maximum crop production a good knowledge of the nature and use of fertilisers is necessary.

What we do know is, that Nature is bountiful and abolition of want throughout the world is capable of achievement. There are signs that the world is slowly, but surely, moving towards an international organisation for the production and distribution of its products so that all may share, all may live in freedom and happiness, in a world of sufficiency, and possibly of plenty.

It has been said that the greatest advance in agriculture in the last twenty years has not been so much in our knowledge of the soil, not in the production of fertilisers, but in the greater output per man. This means that the farm labourer, skilled and unskilled, has become more intelligent. The educational system, so often maligned, has been paying a dividend. In the new countries on the Continent there is, among the people, a will to learn, and facilities for the satisfaction of that desire are being arranged. So also in this country there should be a will to learn, a readiness to try new methods, and a broader education by visits to other countries, as well as by receiving visitors. The cultivation of the soil and the production of food should be a strong link in the chain of friendship among the nations.

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